The tryptophan requirement of growing and finishing barrows[1,2,3]

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ABSTRACT: Five experiments were conducted to determine the true ileal digestible Trp (tidTrp) requirement of growing and finishing pigs fed diets (as-fed basis) containing 0.87% (Exp. 3), 0.70% (Exp. 4), 0.61% (Exp. 5), and 0.52% (Exp. 1 and 2) tidLys during the early-grower, late-grower, early-finisher, and late-finisher periods, respectively. Treatments were replicated with three or four replications, with three or four pigs per replicate pen. Treatment differences were considered significant at $P = 0.10$. Experiment 1 was conducted with 27 pigs (initial and final BW of 78.3 ± 0.5 and 109.8 ± 1.9 kg) to validate whether a corn-feather meal (FM) tidTrp-deficient (0.07%) diet, when supplemented with 0.07% crystalline L-Trp, would result in growth performance and carcass traits similar to a conventional corn-soybean meal (C-SBM) diet. Pigs fed the corn-FM diet without Trp supplementation had decreased growth performance and carcass traits, and increased plasma urea N (PUN) concentration. Supplementing the corn-FM diet with Trp resulted in greater ADG and G:F than pigs fed the positive control C-SBM diet. Pigs fed the corn-FM diet had similar carcass traits as pigs fed the C-SBM diet, but loin muscle area was decreased and fat thickness was increased. In Exp. 2, 60 pigs (initial and final BW of 74.6 ± 0.50 and 104.5 ± 1.64 kg) were used to estimate the tidTrp requirement of finishing pigs. The levels of tidTrp used in Exp. 2 were 0.06, 0.08, 0.10, 0.12, or 0.14% (as-fed basis). Response variables were growth performance, PUN concentrations, and carcass traits and quality. For Exp. 2, the average of the estimates calculated by broken-line regression was 0.104% tidTrp. In Exp. 3, 4, and 5, barrows (n = 60, 60, or 80, respectively) were allotted to five dietary treatments supplemented with crystalline L-Trp at increments of 0.02%. The basal diets contained 0.13, 0.09, and 0.07% tidTrp (as-fed basis) in Exp. 3, 4, and 5, and initial BW of the pigs in these experiments were 30.9 ± 0.7, 51.3 ± 1.1, and 69.4 ± 3.0 kg, respectively. The response variable was PUN, and the basal diet used in Exp. 3 and 4 contained corn, SBM, and Canadian field peas. The tidTrp requirements were estimated to be 0.167% for pigs weighing 30.9 kg, 0.134% for pigs weighing 51.3 kg, and 0.096% for pigs weighing 69.4 kg. Based on our data and a summary of the cited literature, we suggest the following total Trp and tidTrp requirement estimates (as-fed basis): 30-kg pigs, 0.21 and 0.18%; 50-kg pigs, 0.17 and 0.14%; 70-kg pigs, 0.13 and 0.11%; and in 90-kg pigs, 0.13 and 0.11%.

Key Words: Pigs, Requirement, Tryptophan

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Introduction

Tryptophan is an essential AA for growing and finishing pigs (NRC, 1998). In a review of the literature, the NRC (1998) observed total Trp requirement estimates to range from 0.13 to 0.18% for 20- to 50-kg pigs and from 0.09 to 0.17% for 50- to 120-kg pigs. Reasons for this variation may be due to gender, genotype, protein level, Trp digestibility in the feedstuffs, and analytical variation in Trp analysis. Very little research has been conducted on the Trp requirement of growing and finishing pigs since that review. Eder et al. (2003) reported true ileal digestible Trp (**tidTrp**) requirements to be 0.20, 0.17, and 0.12% for gilts weighing 25 to 50, 50 to 80, and 80 to 115 kg, respectively, all of which are greater than the NRC (1998) estimates. Kendall et al. (2003) reported a tidTrp:true ileal digestible lysine

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Table 1. Analyzed amino acid composition of ingredients (%, as-fed basis)[a]

Nutrient	Corn[b]	Corn[c]	FM[d]	FM[c]	CFP[e]	SBM[e]
Arg	0.43	0.38	—	5.77	1.77	3.59
His	0.23	0.22	0.98	0.99	0.51	1.31
Ile	0.26	0.25	4.46	3.96	0.94	2.20
Leu	0.96	0.83	—	6.93	1.60	3.67
Lys	0.25	0.25	2.53	2.26	1.58	2.96
Met	0.16	0.16	—	0.62	0.21	0.71
Cys	0.18	0.18	—	4.96	0.31	0.82
Phe	0.38	0.35	—	4.23	1.04	2.44
Tyr	0.25	0.23	—	2.34	0.65	1.71
Thr	0.28	0.26	4.20	3.73	0.88	1.87
Trp	0.06	0.06	0.78	0.55	0.19	0.68
Val	0.40	0.37	5.72	6.43	1.00	2.35

[a]FM = feather meal; CFP = Canadian field peas; SBM = soybean meal.
[b]Used in Exp. 1, 2, 3, and 4.
[c]Used in Exp. 5.
[d]Used in Exp. 1 and 2. Data not available for some AA.
[e]Used in Exp. 3 and 4.

(**tidLys**) of 0.165 for barrows weighing 91 to 124 kg. Using their tidLys requirement estimate of 0.55% results in a tidTrp requirement estimate of 0.09%, which is slightly less than the NRC (1998) estimate. Guzik et al. (2002) recently reported tidTrp requirement estimates of 0.21, 0.20, and 0.18% for pigs weighing 5 to 7, 6 to 10, and 10 to 16 kg, respectively, all of which are similar to the NRC (1998) estimates. Most requirement studies use growth performance as the main response variable; however, plasma urea N (**PUN**) previously has been used to determine AA requirements (Coma et al., 1995; Knowles et al., 1997; Guzik et al., 2002). Very little research has been conducted on the Trp requirement of pigs using carcass response variables, none has been conducted since the NRC (1998) review, and there is no research using carcass response variables when incremental levels of Trp are fed only during the finishing or late-finishing period. Thus, our objective was to estimate the tidTrp requirement of growing and finishing barrows using PUN, growth performance, and carcass traits as response variables.

Materials and Methods

General

The methodology for all experiments relating to animal care was approved by the Louisiana State University Animal Care and Use Committee.

Five experiments were conducted to estimate the tidTrp requirement of growing and finishing pigs. Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc pigs from the Louisiana State University Agricultural Center Swine Unit were used in each experiment. During the grower period, pigs were housed in a totally enclosed building with 1.83-m × 2.44-m pens and metal slotted floors. During the finishing period, pigs were housed in a curtain-sided building in 1.5-m × 3.0-m pens with total concrete slats. Pigs and their environment were monitored daily. Feed, in mash form, and water were provided on an ad libitum basis throughout the experiments. Pigs in each experiment were allotted to treatments on the basis of weight, and ancestry was equalized across treatments in randomized complete block designs.

The diets in all experiments met or exceeded the nutrient requirements (with the exception of Trp for experimental purposes) of growing or finishing pigs (NRC, 1998). Amino acids were provided at 105% of the ratio relative to Lys (NRC, 1998). The early-grower, late-grower, early-finisher, and late-finisher diets contained 0.87% (Exp. 3), 0.70% (Exp. 4), 0.61% (Exp. 5), and 0.52% (Exp. 1 and 2) tidLys, respectively (Table 1; as-fed basis).

In all experiments, ingredients were analyzed for AA. Amino acid concentrations of ingredients and mixed diets were determined after acid hydrolysis, except for Trp, which was determined after alkaline hydrolysis, and Met and Cys, which were determined after performic acid oxidation (AOAC, 1995; 982.30 E [abc], Chp. 45.3.05) using a high-performance cation exchange resin column (Beckman Systems, Inc., Fullerton, CA). Samples were hydrolyzed for 24 h at 110°C. True digestibility coefficients from NRC (1998) were used for diet formulation.

Experiment 1

A 39-d preliminary experiment was conducted with 27 barrows (initial and final BW of 78.3 ± 0.5 and 109.8 ± 1.9 kg, respectively) to ensure that a corn-feather meal (**FM**) tidTrp-deficient (0.06%) diet, when supplemented with crystalline L-Trp, would result in growth performance, carcass traits, and PUN similar to a conventional corn-soybean meal diet. Pigs were allotted to three dietary treatments, with three replications of three pigs per replicate pen. Treatments comprised 1) FM negative control (**NC**); 2) NC + 0.07% Trp; or 3) corn-soybean meal positive control (**PC**; Table 2).

Table 2. Composition of the basal and positive control diets (%, as-fed basis)

Item	Exp. 1 and 2[a]	Exp. 1	Exp. 3	Exp. 4	Exp. 5
Ingredient					
Corn	85.30	83.39	54.96	79.40	91.20
Soybean meal (47.5% CP)	—	13.17	10.34	6.17	—
Canadian field peas	—	—	30.00	10.00	—
Feather meal	2.43	—	—	—	4.35
Monocalcium phosphate	1.19	0.84	0.74	0.92	0.88
Limestone	1.02	1.07	1.08	1.05	0.90
Fat[b]	—	—	0.66	—	0.29
Salt	0.50	0.50	0.50	0.50	0.50
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[c]	0.38	0.38	0.38	0.38	0.38
Mineral premix[d]	0.10	0.10	0.10	0.10	0.10
Se premix[e]	0.05	0.50	—	—	—
L-Lys·HCl	0.40	—	0.11	0.31	0.40
L-Thr	0.10	—	0.06	0.13	—
L-Ile	0.03	—	—	—	—
DL-Met	—	—	0.07	0.04	—
Cornstarch[f]	8.00	—	0.50	0.50	0.50
Calculated nutrient composition, %[g]					
ME, kcal/kg	3,297	3,297	3,265	3,265	3,265
t Lys	0.59	0.61	1.01	0.78	0.73
t Sulfur AA	0.42	0.50	0.55	0.44	0.56
t Thr	0.44	0.49	0.68	0.53	0.43
t Trp	0.07	0.14	0.16	0.11	0.08
t Ile	0.36	0.52	0.66	0.43	0.41
t Val	0.48	0.64	0.75	0.56	0.61
t His	0.22	0.34	0.41	0.31	0.31
tid Lys	0.52	0.52	0.87	0.70	0.61
tid Sulfur AA	0.35	0.44	0.51	0.39	0.44
tid Thr	0.37	0.41	0.55	0.47	0.34
tid Trp	0.06	0.12	0.13	0.09	0.07
tid Ile	0.32	0.46	0.55	0.37	0.35
tid Val	0.41	0.56	0.62	0.48	0.52
tid His	0.19	0.32	0.36	0.27	0.25

[a]In Exp. 1, 0.07% L-Trp was added to make the diet adequate in Trp.
[b]Provided 99% crude fat, Fat Pak 100, Milk Specialties Co., Dundee, IL.
[c]Vitamin premix provided the following per kilogram of diet: vitamin A, 8,267 IU; vitamin D_3, 2,480 IU; vitamin E, 66 IU; menadione (as menadione pyrimidinol bisulfite complex), 6.2 mg; riboflavin, 10 mg; Ca D-pantothenic acid, 37 mg; niacin, 66 mg; vitamin B_{12}, 45 μg; D-biotin, 331 μg; folic acid, 2.5 mg; pyridoxine, 3.31 mg; thiamine, 3.31 mg; and vitamin C, 83 mg.
[d]Provided the following per kilogram of diet: Zn (zinc sulfate), 127 mg; Fe (ferrous sulfate monohydrate), 127 mg; Mn (manganous sulfate), 20 mg; Cu (copper sulfate), 12.7 mg; and I (calcium iodate), 0.80 mg.
[e]Provided 0.3 mg Se/kg of diet as sodium selenite, Prince Agri Products, Inc., Quincy, IL.
[f]Tryptophan was added in place of cornstarch.
[g]Based on the analysis of the ingredients; t = total; tid = true ileal digestible based on NRC (1998).

Response variables included ADG, ADFI, G:F, conventional carcass characteristics and quality, total body electrical conductivity (**TOBEC**, model MQI-27, Meat Quality, Inc., Springfield, IL) analyses, and PUN concentrations. All pigs were held without feed for 16 h before slaughter.

Carcass Evaluation and Quality. On the day after the growth trial ended, all pigs were slaughtered by exsanguination following electrical stunning at the Louisiana State University Agricultural Center Meats Laboratory. Linear carcass measurements were collected on the left side of the carcass after a 24-h chill at 2°C, as outlined by Matthews et al. (2001). Carcasses were evaluated with TOBEC analysis using equations for calculation of kilograms of carcass fat-free lean and fat content (Higbie et al., 2002). In addition, percentage of acceptable quality lean and kilograms of carcass lean were determined with the equation described by NPPC (1991), which uses 5% estimation for i.m. fat and compensates for unequal BW. Pork quality measurements also were taken as outlined by Matthews et al. (2001).

Blood Sampling. On the day before slaughter, blood was collected via the anterior vena cava, and pigs had access to feed before bleeding. Blood from each pig was placed in 7-mL tubes (Monoject, Sherwood Medical, St. Louis, MO) containing 17.5 mg of sodium fluoride and 14.0 mg of potassium oxalate. Samples were placed on ice for 2 h before centrifugation at 1,500 × g at 4°C for 20 min. Plasma was collected after centrifugation, and samples were frozen until analysis. Plasma was analyzed for PUN concentrations by the methods of Laborde et al. (1995).

Experiment 2

Sixty barrows (initial and final BW of 74.6 ± 0.5 and 104.5 ± 1.6 kg, respectively) were allotted to five dietary treatments derived from the basal diet described in Table 2. Each treatment had three replications with four pigs per replicate pen. The basal diet containing 0.06% tidTrp was supplemented with crystalline L-Trp at 0.02% increments to provide five tidTrp levels of 0.06, 0.08, 0.10, 0.12, or 0.14% (as-fed basis). The experimental diets were fed for 38 d. Pigs were fasted for 16 h before slaughter.

On the day after the growth trial ended, three pigs per replicate pen were selected randomly for slaughter as described previously. As before, response variables were ADG, ADFI, G:F, linear carcass measurements, pork quality, TOBEC analyses, and PUN concentrations. Ham weight and butt-face fat thickness also were recorded, and the ham was evaluated by TOBEC analysis for calculation of kilograms of carcass fat-free lean and fat content (Higbie, 1997).

Experiments 3, 4, and 5

Based on previous research (Coma et al., 1995) and the results from Exp. 1 and 2, PUN was used to estimate the Trp requirement in the remainder of the experiments. In Exp. 3, 4, and 5, barrows (n = 60, 60, or 80, respectively) were allotted to five dietary treatments derived from the basal diets in Table 2. Each treatment was replicated with three (Exp. 3 and 4) or four (Exp. 5) replications of four barrows per replicate pen. In Exp. 3 and 4, Canadian field peas were used along with soybean meal as the protein sources. Previously, Guzik et al. (2002) validated a Canadian field pea-based diet for use in determining Trp requirements of weanling pigs. Diets were supplemented with crystalline L-Trp at increments of 0.02% to give five treatments containing (as-fed basis) 0.13, 0.15, 0.17, 0.19, or 0.21% (Exp. 3); 0.09, 0.11, 0.13, 0.15, or 0.17% (Exp. 4); or 0.07, 0.09, 0.11, 0.13, or 0.15% (Exp. 5) tidTrp (Table 2). Pigs had an initial BW of 30.9 ± 0.7 (Exp. 3), 51.3 ± 1.1 (Exp. 4), or 69.4 kg ± 3.0 (Exp. 5). Pigs were fed a conventional grower diet adequate in all nutrients before the experiment began. The experimental diets were fed for 7 d.

Blood Sampling. The day before the treatment diets were fed and at the end of Exp. 3, 4, and 5, blood was collected as described previously. The PUN concentrations in the initial blood sample were used as a covariate for the final PUN for statistical analysis. Pigs had access to feed before bleeding. Plasma was analyzed for PUN concentrations as described previously.

Statistical Analyses

In each experiment, data were analyzed as randomized complete block designs using the GLM procedures of SAS (SAS Inst., Inc., Cary, NC). In Exp. 1, treatments were separated using the PDIFF option of SAS when the overall treatment effects were different ($P = 0.10$). In Exp. 2, 3, 4, and 5, Trp effects were evaluated by linear and quadratic contrasts, and the two-slope, broken-line regression model was used for response variables to obtain an estimate of the tidTrp requirement (Robbins, 1986). The broken-line model could not be used to estimate requirements for some response variables due to lack of response to Trp or because there was no plateau in the data. Treatment differences were considered significant at $\alpha = 0.10$. The pen of pigs served as the experimental unit for all data.

Table 3. Growth performance and plasma urea N concentration of finishing barrows fed a diet deficient or adequate in tryptophan, Exp. 1[a]

Item	Negative control	Negative control + Trp	Positive control	SEM
ADG, kg	0.63[b]	0.98[c]	0.81[d]	0.04
ADFI, kg	3.58	3.28	3.55	0.06
G:F	0.18[b]	0.30[c]	0.23[d]	0.01
PUN, m*M*	2.90[b]	1.40[c]	1.49[c]	0.13
Final BW, kg	102.9[b]	116.6[c]	109.8[d]	1.8

[a]Data are means of three replicates of three barrows per replicate. Initial BW was 78.3 kg. Average daily feed intake and G:F are on an as-fed basis. PUN = plasma urea N.

[b,c,d]Row means with different superscripts differ, $P = 0.10$.

Results

Experiment 1

Pigs fed the NC diet supplemented with crystalline L-Trp had an increased ($P = 0.10$) ADG and G:F compared with pigs fed the PC diet (Table 3). Pigs fed the NC diet without L-Trp supplementation had a decreased ($P = 0.10$) ADG and G:F and an increased ($P = 0.10$) PUN compared with pigs fed the NC + Trp diet or the PC diet.

Pigs fed the NC + Trp diet had carcass traits similar to those of pigs fed the PC diet, with the exception of loin muscle area, which was increased ($P = 0.10$), and average backfat thickness, which was decreased ($P = 0.10$), in pigs fed the PC diet relative to pigs fed the NC or NC + Trp diets (Table 4). Kilograms of carcass fat-free lean and NPPC kilograms of carcass lean were greater ($P = 0.10$) in pigs fed the PC or NC + Trp diet than in pigs fed the NC diet. Tenth-rib backfat thickness, total carcass fat, and CIE a* were increased ($P = 0.10$), and percentage acceptable quality lean were decreased ($P = 0.10$) in pigs fed the NC +Trp diet relative to those fed the PC or the NC diet.

Experiment 2

Average daily gain and G:F were increased linearly ($P = 0.10$) as tidTrp level increased (Table 5). Plasma urea N decreased linearly ($P = 0.10$) with increasing levels of tidTrp.

Table 4. Carcass traits of finishing barrows fed diets deficient or adequate in tryptophan, Exp. 1[a]

Item	Negative control	Negative control + Trp	Positive control	SEM
Conventional measurements				
Carcass weight, kg	76.30[i]	87.89[j]	83.88[k]	1.19
Dressing percent	74.10	75.06	75.54	0.65
Carcass length, cm	81.00	82.55	81.42	0.60
Loin muscle area, cm^2	42.26[i]	45.44[i]	50.30[j]	1.41
Tenth-rib backfat, cm	1.86[i]	2.21[j]	1.81[i]	0.07
Average backfat, cm	2.68[i]	2.85[e]	2.48[f]	0.11
TOBEC[b]				
Carcass fat-free lean, kg	37.31[i]	43.50[j]	42.67[j]	1.18
Carcass fat-free lean, %	49.09	49.71	50.86	1.22
Total carcass fat, kg	19.62[i]	23.31[j]	20.20[i]	0.82
Carcass fat, %	25.49	26.41	24.03	0.98
NPPC[c]				
Total carcass lean, kg	41.91[i]	46.55[j]	47.79[j]	0.88
Percentage of acceptable quality lean	55.00[i]	53.31[j]	56.83[k]	0.56
Pork quality				
45-min pH	5.84	5.69	5.95	0.09
24-h pH	5.42	5.42	5.40	0.05
Color[d]	2.22	2.17	2.44	0.18
Marbling[e]	1.44	1.39	1.19	0.18
CIE L*[f]	51.70	52.54	51.43	1.66
CIE a*[g]	4.55[i]	6.22[j]	4.76[i]	0.43
CIE b*[h]	10.20	11.50	10.12	0.57
Drip loss, %	4.72	5.84	3.98	1.00
Cook loss, %	20.35	18.92	21.35	1.05
Total loss, %	25.07	24.76	25.33	1.07
Shear force, kg	2.60	2.99	2.77	0.18

[a]Data are means of three replicates of three barrows per replicate pen. Initial and final BW were 78.3 and 109.8 kg, respectively.
[b]Calculated with total body electrical conductivity (TOBEC) analysis with equations from Higbie et al. (2002).
[c]Calculated using the equation described by the NPPC (1991), which uses a 5% estimation for intramuscular fat and compensates for unequal BW.
[d]Color: 1 = pale and 6 = dark purplish red.
[e]Marbling: 1 to 10 = 1 to 10% i.m. fat, respectively.
[f]CIE = Commission internationale de I'Eclairage. L* = measurement of lightness to darkness, with a higher value indicating a lighter color.
[g]a* = measurement of greenness to redness, with a higher value indicating a redder color.
[h]b* = measurement of blueness to yellowness, with a higher value indicating a more yellow color.
[i,j,k]Row means with different superscripts differ, $P = 0.10$.

Table 5. Growth performance and plasma urea N concentration of finishing barrows fed graded levels of tryptophan, Exp. 2[a]

	True ileal digestible Trp, %					
Item	0.06	0.08	0.10	0.12	0.14	SEM
ADG, kg[b]	0.69	0.75	0.93	0.90	0.85	0.04
ADFI, kg	3.69	3.52	3.30	3.36	3.46	0.06
G:F[b]	0.19	0.21	0.28	0.27	0.24	0.01
PUN, mM[bc]	2.85	2.02	1.56	1.46	1.64	0.13
Final BW, kg[bd]	98.5	105.0	105.1	107.8	106.3	1.6

[a]Data are means of three replicates of four barrows per replicate pen. Initial BW was 74.6 kg. Average daily feed intake and G:F are on an as-fed basis.
[b]Trp linear, $P = 0.10$.
[c]PUN = plasma urea N.
[d]Trp quadratic, $P = 0.10$.

Table 6. Carcass traits of finishing barrows fed graded levels of tryptophan, Exp. 2[a]

	True ileal digestible Trp, %					
Item	0.06	0.08	0.10	0.12	0.14	SEM
Linear measurements						
Carcass weight, kg[bc]	75.17	79.73	81.83	84.22	83.30	1.44
Dressing percent[b]	76.25	78.06	77.79	78.00	78.09	0.59
Carcass length, cm	82.13	83.50	83.93	83.61	83.61	0.61
Loin muscle area, cm^2 [b]	43.04	44.21	45.86	46.46	47.99	0.54
Tenth-rib backfat, cm[b]	1.78	1.99	2.07	2.17	2.24	0.10
Average backfat, cm[b]	2.37	2.48	2.49	2.67	2.77	0.08
Ham weight, kg[b]	8.68	9.25	9.06	9.38	9.39	0.21
Ham butt-face fat, cm	0.92	0.97	1.02	0.86	1.02	0.09
TOBEC[d]						
Carcass fat-free lean, kg[b]	39.14	40.57	42.53	43.18	43.62	1.20
Carcass fat-free lean, %	49.12	49.52	50.13	50.46	50.47	1.23
Total carcass fat, kg[b]	19.64	19.98	20.01	22.54	23.20	0.81
Carcass fat, %	28.99	30.12	30.68	31.20	30.45	1.00
NPPC[e]						
Total carcass lean, kg[bc]	44.55	47.90	48.37	49.67	49.50	0.71
Percentage of acceptable quality lean	55.13	54.24	54.41	54.36	54.96	0.46
Pork quality						
45-min pH	5.83	5.97	5.82	5.83	5.79	0.09
24-h pH	5.56	5.64	5.60	5.54	5.64	0.03
Color[f]	2.22	2.27	2.34	2.33	2.39	0.19
Marbling[g]	1.38	1.33	1.24	1.21	1.18	0.16
CIE L*[h]	58.38	55.51	61.14	55.63	58.02	2.74
CIE a*[i]	6.28	9.10	5.73	7.17	6.97	1.80
CIE b*[j]	11.55	10.86	11.86	12.39	11.64	0.86
Drip loss, %	4.35	4.65	5.21	5.47	4.94	1.01
Cook loss, %	20.14	20.85	21.01	19.95	20.68	1.06
Total loss, %	24.49	25.50	26.22	25.42	25.62	1.09

[a]Data are means of three replicates of three barrows per replicate pen. Initial and final BW were 74.6 and 104.5 kg, respectively.
[b]Trp linear, P = 0.10.
[c]Trp quadratic, P = 0.10.
[d]Calculated with TOBEC analysis with ham equations from Higbie (1997).
[e]Calculated using the equation described by the NPPC (1991), which uses a 5% estimation for intramuscular fat and compensates for unequal BW.
[f]Color: 1 = pale and 6 = dark purplish red.
[g]Marbling: 1 to 10 = 1 to 10% i.m. fat, respectively.
[h]CIE = Commission internationale de I'Eclairage. L* = measurement of lightness to darkness, with a higher value indicating a lighter color.
[i]a* = measurement of greenness to redness, with a higher value indicating a redder color.
[j]b* = measurement of blueness to yellowness, with a higher value indicating a more yellow color.

Dressing percent, loin muscle area, 10th-rib backfat thickness, average backfat thickness, ham weight, kilograms of carcass fat-free lean, and NPPC kilograms of carcass lean were linearly increased (P = 0.10) with increasing levels of tidTrp (Table 6). There was a Trp quadratic effect (P = 0.10) in kilograms of carcass fat-free lean.

Broken-line analysis estimated the tidTrp requirement to be 0.094, 0.109, 0.103, 0.105, and 0.108% (as-fed basis) for ADG, G:F, PUN concentrations, carcass fat-free lean, and NPPC kilograms of lean, respectively. The average of these values yields an estimate of 0.104% tidTrp (0.12% total Trp; as-fed basis) for optimal growth of finishing pigs weighing 74.6 to 104.5 kg.

Experiment 3

The 30.9-kg Pigs. Plasma urea N was decreased linearly (P = 0.01) and quadratically (P = 0.03) as the tidTrp content was increased from 0.13 to 0.21% in barrows weighing 30.9 kg (Table 7). Broken-line regression analysis estimated the tidTrp requirement to be 0.167% (0.20% total Trp; as-fed basis) to minimize PUN of barrows.

Experiment 4

The 51.3-kg Pigs. Plasma urea N was decreased linearly (P = 0.01) and quadratically (P = 0.03) as the tidTrp content increased from 0.09 to 0.17% in barrows weighing 51.3 kg (Table 7). Broken-line regression analysis estimated the tidTrp requirement to be 0.134% (0.15% total Trp; as-fed basis) to minimize PUN of barrows.

Experiment 5

The 69.4-kg Pigs. Plasma urea N was decreased quadratically (P = 0.03) as the tidTrp content increased

Table 7. Plasma urea nitrogen concentrations of barrows weighing 30.9, 51.3, and 69.4 kg and fed graded levels of true ileal digestible tryptophan, Exp. 3, 4, and 5[a]

Item	True ileal digestible Trp, %						
Exp. 2 (30.9 kg)	0.13	0.15	0.17	0.19	0.21	SEM	REQ[b]
PUNI, m*M*	3.61	3.60	3.90	2.94	3.26	0.41	—
PUNF, m*M*[cd]	3.54	2.13	1.07	1.58	2.12	0.18	0.17
	True ileal digestible Trp, %						
Exp. 4 (51.3 kg)	0.09	0.11	0.13	0.15	0.17	SEM	
PUNI, m*M*	3.64	3.72	3.67	3.53	2.99	0.39	—
PUNF, m*M*[cd]	3.45	2.36	1.13	1.87	2.25	0.20	0.13
	True ileal digestible Trp, %						
Exp. 5 (69.4 kg)	0.07	0.09	0.11	0.13	0.15	SEM	
PUNI, m*M*	2.66	2.68	2.77	2.69	3.31	0.26	—
PUNF, m*M*[d]	2.93	2.30	2.18	2.40	2.42	0.17	0.10

[a]Data are means of three (Exp. 3 and 4) or four (Exp. 5) replicates of four barrows per replicate pen. PUNI = initial plasma urea N; PUNF = final plasma urea N. The PUNI was used as a covariate for the PUNF data.
[b]REQ = true ileal digestible requirement estimate by the broken-line model.
[c]Trp linear ($P = 0.01$) effect.
[d]Trp quadratic ($P = 0.03$) effect.

from 0.09 to 0.17% in barrows weighing 51.3 kg (Table 7). Broken-line regression analysis estimated the tidTrp requirement to be 0.096% (0.11% total Trp; as-fed basis) to minimize PUN of barrows.

Discussion

Experiment 1 was conducted to validate a Trp-deficient diet that subsequently could be used to estimate the Trp requirement of pigs. Much of the research conducted to estimate nutrient requirements has used experimental diets that were not validated. To make valid requirement estimates, one must know that the experimental diet, when supplemented with the nutrient under investigation, results in growth performance and carcass traits similar to a diet that is thought to be typical of the industry or that results in maximum performance. In our study, pigs fed the experimental diet had growth performance and many (but not all) carcass response variables that were equal to or greater than those of pigs fed the PC diet. Thus, we concluded that the diet was acceptable for subsequent requirement studies, especially those based on growth performance.

Experiment 2 was conducted to validate the use of PUN as a method of estimating the Trp requirement for the remainder of the experiments in this study. The estimate obtained from the PUN method (0.103% tidTrp) was similar to the estimates obtained for ADG (0.094% tidTrp), G:F (0.109% tidTrp), kilograms of lean (0.105% tidTrp), and NPPC kilograms of lean (0.108% tidTrp), indicating that PUN could be used to determine Trp requirements for swine, which agrees with the findings of Coma et al. (1995), Knowles et al. (1997), and Guzik et al. (2002).

In our study with barrows, the tidTrp requirement generally decreased as BW increased. The tidTrp requirement estimates (as-fed basis) were 0.167% (0.20% total Trp), 0.134% (0.15% total Trp), 0.096% (0.11% total Trp), and 0.104% (0.12% total Trp) in 30.9, 51.3, 69.4, and 74.6 to 104.5 kg pigs, respectively. These Trp requirement estimates obtained are in agreement with some previous research but not all.

There are several estimates in the literature of the Trp requirement of pigs averaging approximately 30 kg. Our estimate of 0.167% tidTrp (0.20% total Trp) for 30.9-kg pigs agrees well with the estimate of Schutte et al. (1995), who reported a total Trp requirement of 0.21% in 20- to 40-kg pigs. Schutte et al. (1995) indicated that this value corresponded to an apparent ileal digestible Trp value of 0.177%. The estimates by Schutte et al. (1995) were based on results for maximum gain and feed efficiency. Eder et al. (2003) reported a higher tidTrp requirement estimate of 0.20% (0.23% total Trp) in 25- to 50-kg pigs, but these authors suggested that this requirement may be an overestimate because of the statistical methods used. Other researchers have reported lower total Trp requirement estimates with pigs of similar weights: 0.16% (15- to 40-kg pigs; Henry et al., 1986), 0.17% (18- to 34-kg pigs; Russell et al., 1983), 0.135% (20- to 45-kg pigs; Batterham and Watson, 1985), 0.13% (22- to 50-kg pigs; Burgoon et al., 1992), and 0.13% (25- to 45-kg pigs; Lin et al., 1986).

The considerable variation in the estimates of the total Trp requirement of pigs may be due to the use of total Trp requirement estimates rather than some measure of digestible Trp. It is difficult to estimate Trp digestibility in the diets used in some of the studies, and when digestibility estimates are provided, methodology is dissimilar. Methods include estimating digestibility using values provided in tables as we did, or directly determining the apparent ileal or apparent fecal digestibility. The requirement estimates range from 0.13 to 0.23% total Trp; and from 0.10 to 0.20% tidTrp. Thus, comparison of estimates on the basis of digestibility does not decrease the variation.

The statistical methodology used to estimate the requirement affects the requirement estimate, with estimates from the broken-line method almost always resulting in requirement estimates lower than those estimated from curvilinear methods. Eder et al. (2003) used the curvilinear method and indicated that this method would "overestimate rather than underestimate the requirement." Fitting their data to the broken-line method results in requirement estimates of approximately 0.15% for gain and 0.12% for feed conversion. However, neither gain nor feed conversion clearly reached a plateau. We used the broken-line method and report a relatively high Trp requirement, whereas Burgoon et al. (1992) used the broken-line method but reported one of the lowest requirements. Thus, variation in these Trp requirement estimates could be decreased using similar statistical methodology, but similar statistical methodology does not eliminate the variation.

The response variable used to estimate the requirement will likely affect the requirement. Most researchers used some measure of growth response; the highest and lowest Trp requirement estimates used growth response variables. Similarly, we used PUN as the response variable, whereas Lin et al. (1986) used oxidation of an AA as the response variable, both of which are based on the principle of AA catabolism. However, we report one of the higher estimates, and Lin et al. (1986) reported one of the lowest estimates. Thus, the response variable used does not seem to decrease the variation in the requirement estimates. However in our data, some variables (carcass length, ham butt face fat thickness, NPPC percentage of lean, and all pork quality data did not respond to graded levels of dietary tidTrp. On the other hand, some variables (dressing percent, fat thickness, loin muscle area, and ham weight) responded linearly but did not plateau.

Lastly, the level of Lys in the diet will affect the Trp requirement. If Lys is deficient in the diet, the Trp requirement estimate will be decreased. In reviewing the literature, the total Lys levels used ranged from 0.70 to 1.09% for pigs near this weight. The Trp requirement estimates of 0.13, 0.13, and 0.135% used total Lys levels of 0.70 (Lin et al., 1986), 0.90 (Burgoon et al., 1992), and 1.00% (Batterham and Watson, 1985), respectively, which suggests that Lys level may not be a factor in the variable estimates. However, all the higher Trp requirement estimates used total Lys levels in the basal diet in excess of 1.00% (our data; Schutte et al., 1995; Eder et al., 2003). The NRC (1998) suggested a requirement of 0.95% total Lys for pigs weighing 20 to 50 kg. Although there are exceptions, the higher Trp requirement estimates were obtained in pigs fed a basal diet that contained Lys levels at or above the NRC requirement, and these higher estimates are the most recent. Assuming that the higher Trp requirement estimates are a result of an increased capacity for lean gain, which requires a higher level of Lys, an average of these estimates is a reasonable estimate of the Trp requirement of pigs produced currently. Thus, the total Trp requirement of pigs averaging 30 kg is estimated to be 0.21 or 0.18% tidTrp (as-fed basis) based on our data and the estimates from Schutte et al. (1995) and Eder et al. (2003).

Our estimate of the tidTrp of 0.134% (0.15% total Trp) for pigs weighing 51 kg is similar to the estimate of 0.165% total Trp reported by Lenis et al. (1990) in 35- to 65-kg pigs. Möhn and Susenbeth (1994) reported that the total Trp requirement for 30- to 60-kg was at least 0.18%, but there was no plateau in the data. The Lys levels in the basal diets used in the research just noted were all above the NRC (1998) suggested requirements. Lenis et al. (1990) used boars and gilts, and they should require greater levels of AA than the barrows used in our research and the research of Möhn and Susenbeth (1994). These estimates are relatively similar, and an average of these estimates indicates a total Trp requirement of 0.165%. Because of the dietary constituents used by these researchers, it is extremely difficult to estimate a tidTrp requirement, but using 85% of the total Trp requirement to estimate tidTrp equates to 0.14% tidTrp.

Our estimate of the tidTrp of 0.096% (0.11% total Trp) for pigs weighing 69 kg is higher than the estimate of Burgoon et al. (1992) of 0.06% for apparent ileal Trp digestibility or 0.09% total Trp for pig's weighing 55 to 97 kg. However, Eder et al. (2003) reported a tidTrp of 0.171% (0.20% total Trp) for pigs weighing 50 to 80 kg. As with the Trp requirement estimates for 30-kg pigs, the Trp requirement estimates of pigs with an average weight of approximately 70 kg varies considerably from 0.06 to 0.17% apparent and/or true ileal digestibility. It is unlikely that there is a threefold difference in the actual Trp requirement of pigs weighing approximately 70 kg. Consequently, one must consider that some of these estimates are in error and that they do not reflect biological variation due to gender, diet digestibility, or capacity for lean gain. An average of these three estimates is 0.13% total Trp and 0.11% tidTrp (as-fed basis), both of which are similar to our estimates.

Our estimate of the tidTrp requirement of 0.104 (0.12% total Trp) for 75- to 105-kg pigs is similar to the estimate of 0.091% by Kendall et al. (2003) in 91- to 124-kg barrows. This tidTrp requirement estimate is based on the authors' report of a Trp:Lys ratio of 0.165, and a dietary tidLys level of 0.55%, which the authors indicate is very close to the tidLys requirement for the pigs used in this research (G. L. Allee; Univ. of Missouri, Columbia, personal communication). Eder et al. (2003) reported estimates of 0.122% for gain and 0.084% for

N retention in pigs weighing 80 to 115 kg. No total estimate could be made from the data of Kendall et al. (2003). Using the higher estimate of Eder et al. (2003), an average of all these estimates is 0.14% total or 0.11% tidTrp (as-fed basis).

The average estimates of the Trp requirement of pigs weighing 70 and 90 kg are basically the same, which is in agreement with our data. This response was not expected, and it may be due to inaccurate estimates of the Trp requirement of pigs weighing 70 kg because of the large variation in that estimate within the literature.

We have summarized the data on the Trp requirement of growing and finishing pigs. Based on the assumption that lean gain of pigs has increased during the last 25 yr, we have chosen not to use requirement estimates published before 1980 in our summary of the data. Thus, based on our data and a summary of the cited literature, we suggest the following total Trp and tidTrp requirement estimates (as-fed basis): 30-kg pigs, 0.21 and 0.18%; 50-kg pigs, 0.17 and 0.14%; 70-kg pigs, 0.13 and 0.11%; and 90-kg pigs, 0.13 and 0.11%. Because we do not expect the Trp requirement, expressed as a percentage of the diet, to increase as pigs increase in weight, we suggest the same requirement for 70- and 90-kg pigs.

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